Selected Topics Communications and Mobile Computing (Smart Health)

TU Graz

University of Notre Dame

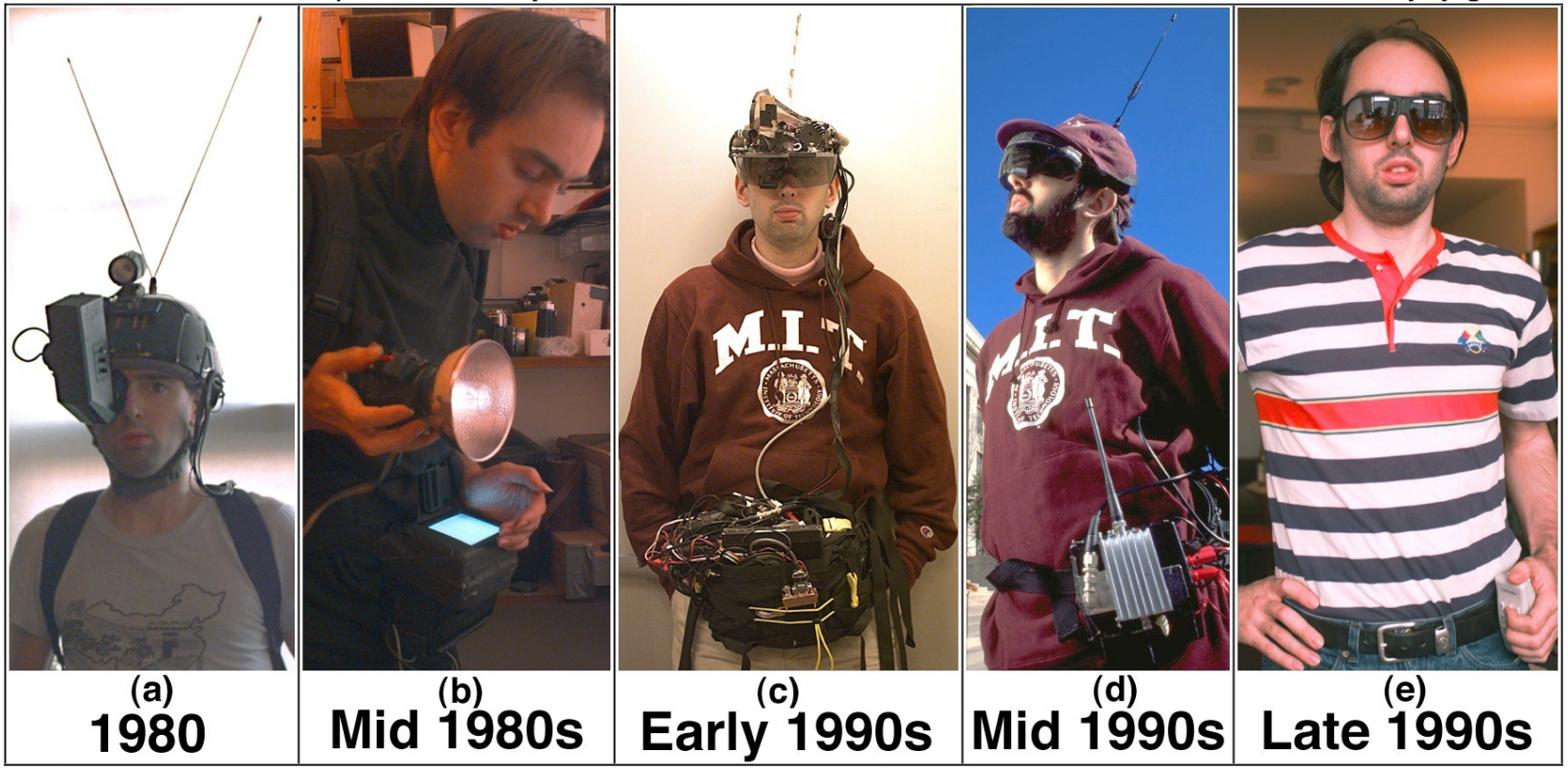
The Early Days…

Steve Mann

- Considered to be inventor of wearable computing.
- ”Wearable Computing Project” at MIT (1991).
- World’s first covert wearable computer with camera and display concealed in ordinary eyeglasses (1995).
- PhD from MIT (1997).
- Works at University of Toronto.

Steve Mann

Steve Mann's "wearable computer" and "reality mediator" inventions of the 1970s have evolved into what looks like ordinary eyeglasses.



What is Wearable Computing?

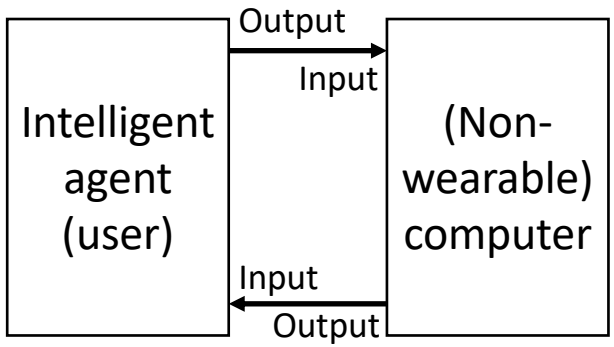
- "A wearable computer is a computer that is ***subsumed into the personal space of the user***, controlled by the user, and has both operational and interactional constancy, i.e. is always on and always accessible. Most notably, it is a device that is always with the user, and into which the user can always enter commands and execute a set of such entered commands, and in which the user can do so while walking around or doing other activities"

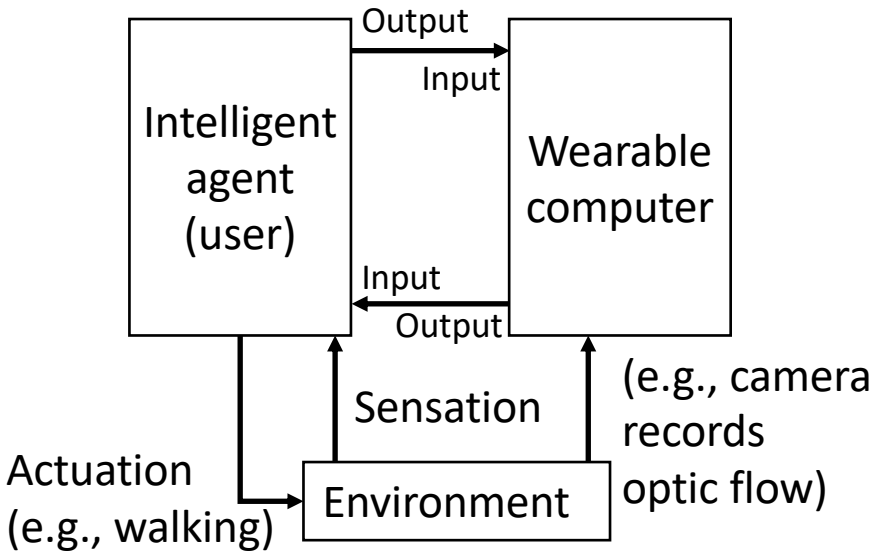
What is Wearable Computing?

Seven attributes of wearable computing [Steve Mann, 1998]:

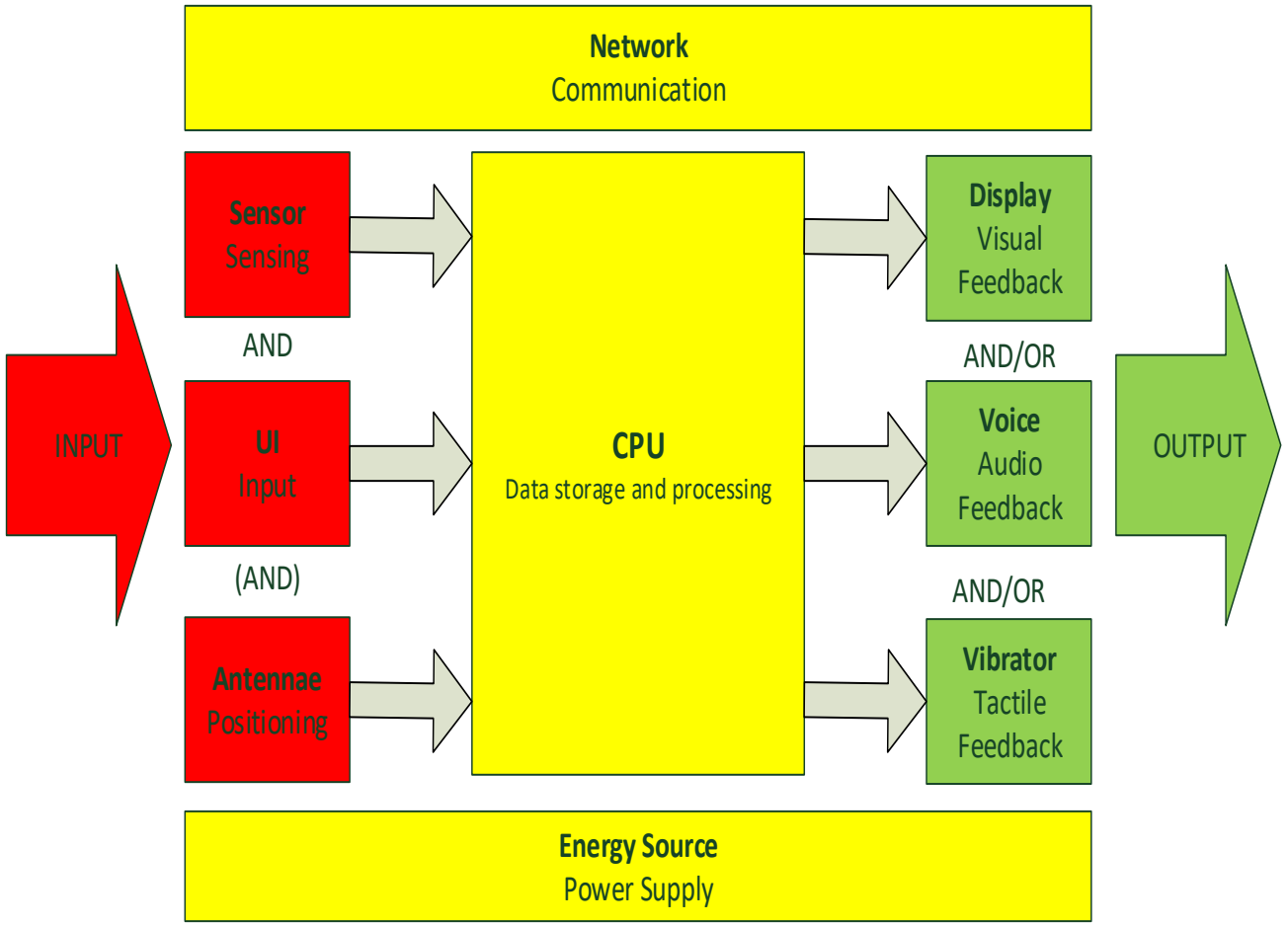
1. **Unmonopolizing** of the user's attention. User can attend to other events.
2. **Unrestrictive** to the user. Allows interaction while user carries out normal functions.
3. **Observable** by the user. As the system is being worn, there is no reason why the wearer cannot be aware of it continuously (but this contrasts with #1).
   - Different phrasing: User can identify computational and non-computational components of their clothing.
4. **Controllable** by the user; user can take control (on/off/configure) at any time.
5. **Attentive** to the environment; can enhance the user's environment and situational awareness.
6. **Communicative** to others; can be used as a communications medium.
7. **Shares the same physical and situational context as the user.**

What is Wearable Computing?





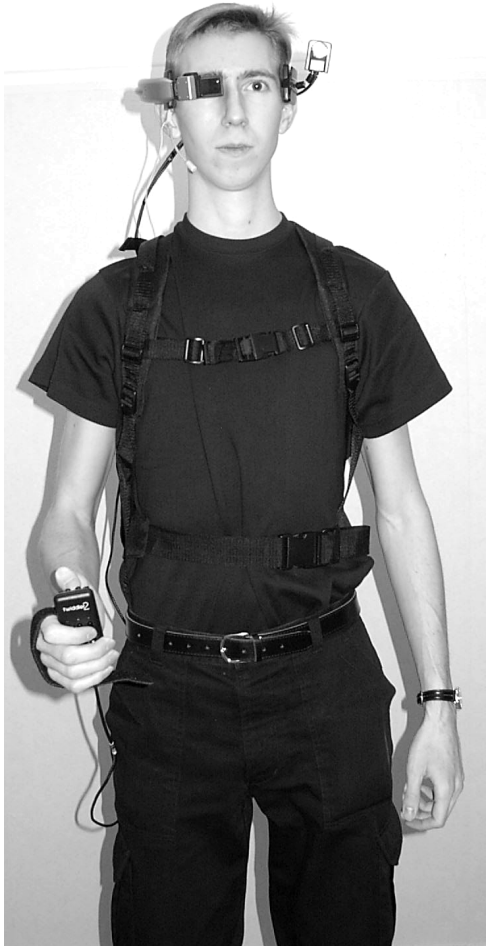
What is Wearable Computing?



Wearable vs. Ubiquitous/Pervasive

- Ubiquitous computing
  - Computer/sensors embedded in the **environment**
- Wearable computing:
  - Computers/sensors on **people**
- Complimentary

Components of a Wearable Device

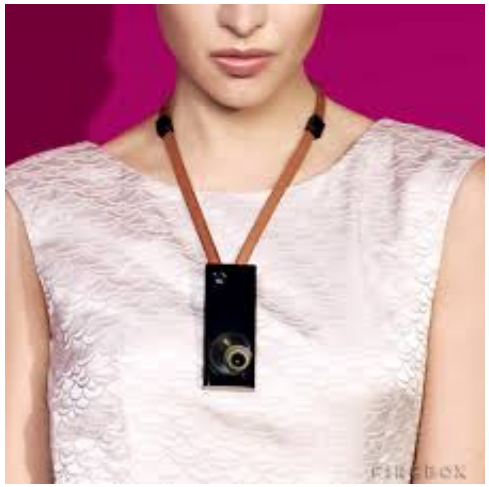


Head-Mounted Display (HMD)

- Small screen, typically covering one or both of your eyes.
- Works like an ordinary monitor, providing an image floating in the air in front of you.
- Transparent vs opaque.

Camera (& Sensors)

- Suitable placement
  - Head, follows user's gaze.
  - Shoulder, more stable.

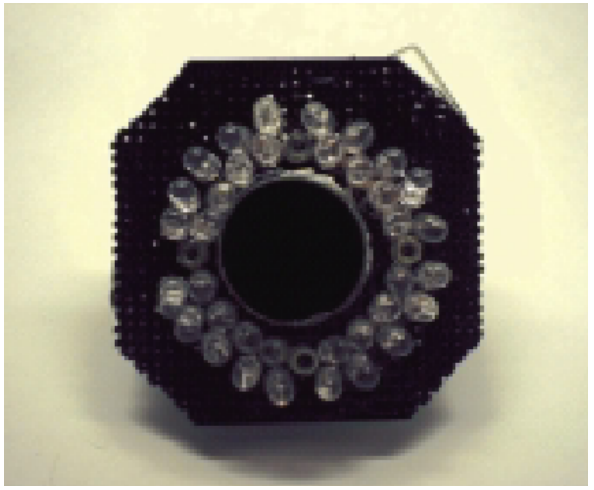


Input Device

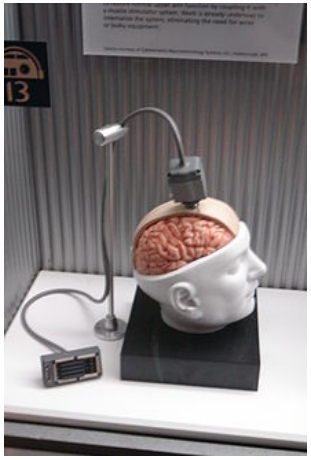
- Keyboard
  - Canesta's IR keyboard
  - Arm-strapped keyboard
  - FrogPad
  - Twiddler chording keyboard
- Mouse
  - Twiddler

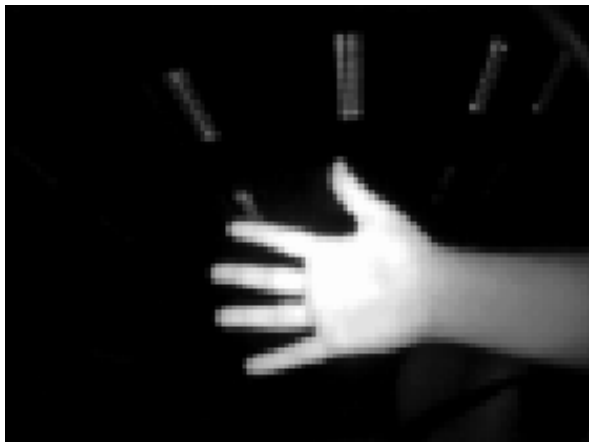
Input Device

- BrainGate
- Gestures
  - Gesture pendant (controlling smart homes)
- Voice recognition
  - Siri, Alexa, …



- Multi-modal interfaces





Output Device

- Sight – Visual output
  - HMD, wristwatch...
- Hearing – Audio/sound/speech/music
  - Speakers, earplug/headset...
- Touch – Tactile feedback
- Taste and smell

The Computer Itself

- Anything small, low-power, but powerful enough
  - Embedded computers
  - Smartphones
  - Smartwatches

Network Connection

- Benefits of having a network
  - Access to the Internet
  - Communication
  - Localization
- Wireless network connection
  - WLAN
  - 3G, 4G, LTE
  - Bluetooth, ZigBee
  - InfraRed

Challenges

- Connecting all pieces
  - Wires (embedded into clothing?), wireless (security?), body as conduit
- Power supply
  - Batteries (rechargeable; solar power)
  - Human powered devices
    - Body heat, 0.6 – 4.8W (wetsuit clothes)
    - Breath, 0.4 – 2.5W (pressure mask)
    - Blood pressure, 0.2W
    - Limb motion, 0.3 – 1.5W
    - Finger motion, 0.019W (keyboard typing)
    - **Walking, 5 – 8W** (shoe generator)
- Heat dissipation

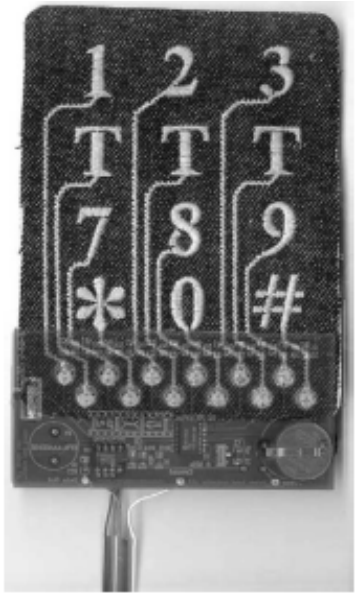


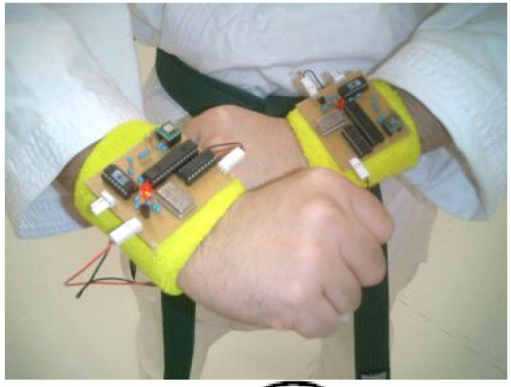
Figure 4: Functional chording keyboard embroidered into a jacket. *Photo courtesy of Rehmi Post and Maggie Orth*

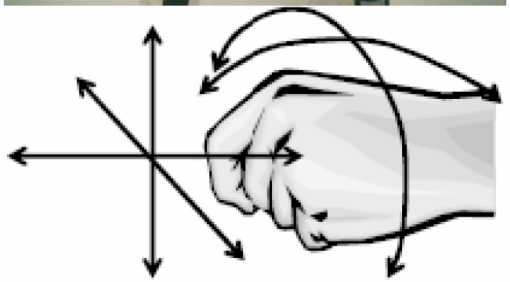
Examples

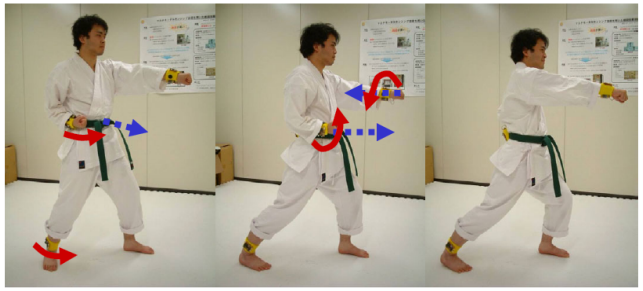
- Technicians
  - Blueprints, etc.
- Field workers
  - Access to information given by remote experts.
- Military personnel
  - Soldiers, monitoring health, equipment, etc.
  - Maps and terrain.
  - Infrastructure (sewers, roads) in urban areas.
- Researchers

Examples

- **Wearables for sports training**
- Karate trainees are instrumented with acceleration sensors.
- Sensor data is translated directly into sound output.
- Trainees can now ‘hear’, as well as see instructor’s movements.
- Trainees can also hear themselves: attempt to match own sound to sound of instructor.
- Martial arts training is about reproducing patterns over time, not just matching static poses; therefore, sound is a useful sensory stimuli to introduce to training.
- Result: Trainees with system tended to learn faster than trainees without system.







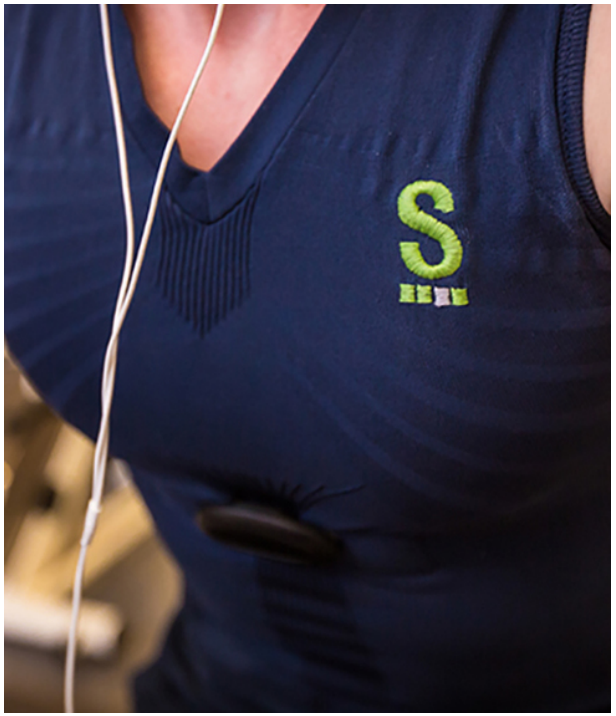
Examples

- **Wearables for the military: Future Force Warrior (FFW)**
- Onboard physiological/medical sensor suite to accelerate casualty care
- Netted communications to maximize robustness and integration of small teams
- Embedded training (similar to martial arts example?)
- Enhanced situational awareness (heads-up display?)
- Synchronized firing of weapons from team
- Bone conduction technology: “talking and speaking without sound or hearing”

Examples: Smartwatches & Trackers

Examples: Fitness & Health

- http://www.sensoriainc.com/



Examples: Fitness & Health

- Hexoskin Clothing
- http://www.gizmag.com/hexoskin-sensor-t-shirt-body-metrics/29098/

Applications

- **Mediated Reality**
  - Experiencing the world through the computer
  - Allows computer to process the sensory cues before reaching the user
    - E.g., block commercial billboards
- **Augmented Reality**
  - Overlaying virtual information on the real world
    - E.g., allow architects to build virtual houses
    - E.g., Pokemon Go
- Both realities can enhance your senses

Applications – Augmented Memory

- Trivial example, finding your way
  - ”Where did I park my car?”
- Camera on your body records the way
- Replay helps you find your way back
  - Only key events need to be recorded
  - Example: Intersections at a car park

Applications – Augmented Memory

- Elderly or people with poor memory
  - Remember name and face of people
    - Image processing can recognize a face and map it to the person's name and affiliation
  - How should it be presented?

Applications – Annotated Reality

Applications - Advertising

Applications - Entertainment

Applications - Entertainment

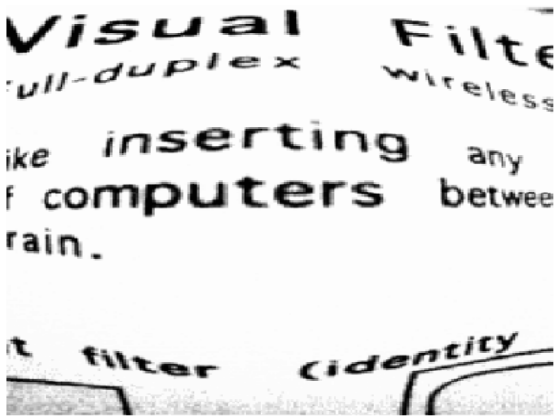
PrioVR gaming

Applications – Aiding the Visually Disabled

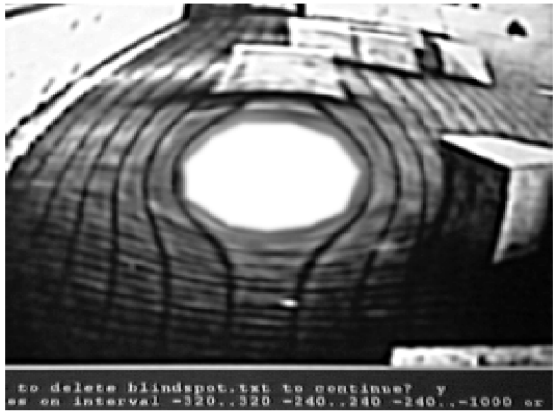
- Some forms of low vision can not be alleviated by use of ordinary glasses
  - User wears non-transparent glasses with integrated displays, experiences the world through a camera
  - Computer processed video stream
    - Enhance contrast
    - Adjust colors
    - Night vision
    - Enlarged view

Applications – Aiding the Visually Disabled

- Fisheye lense for reading text.



- Remapping around blind spots.



Applications – Additional Vision Tricks

- ”Edgertonian” eyes
  - Freeze-frame effect, fast shutter
    - Reading text on a tire of a speeding car
    - Clearly seeing the rotor blades of a helicopter
    - Counting the number of bolts holding an airplane rotor together in mid-air
    - Plus lots of other interesting effects

    - https://www.youtube.com/watch?v=yr3ngmRuGUc

Applications – Additional Vision Tricks

- Giant's eyes
  - Enhances depth perception of distant objects

Applications – First Response

Applications – Social software

Usually designed for urban settings; interface to groups or individuals.

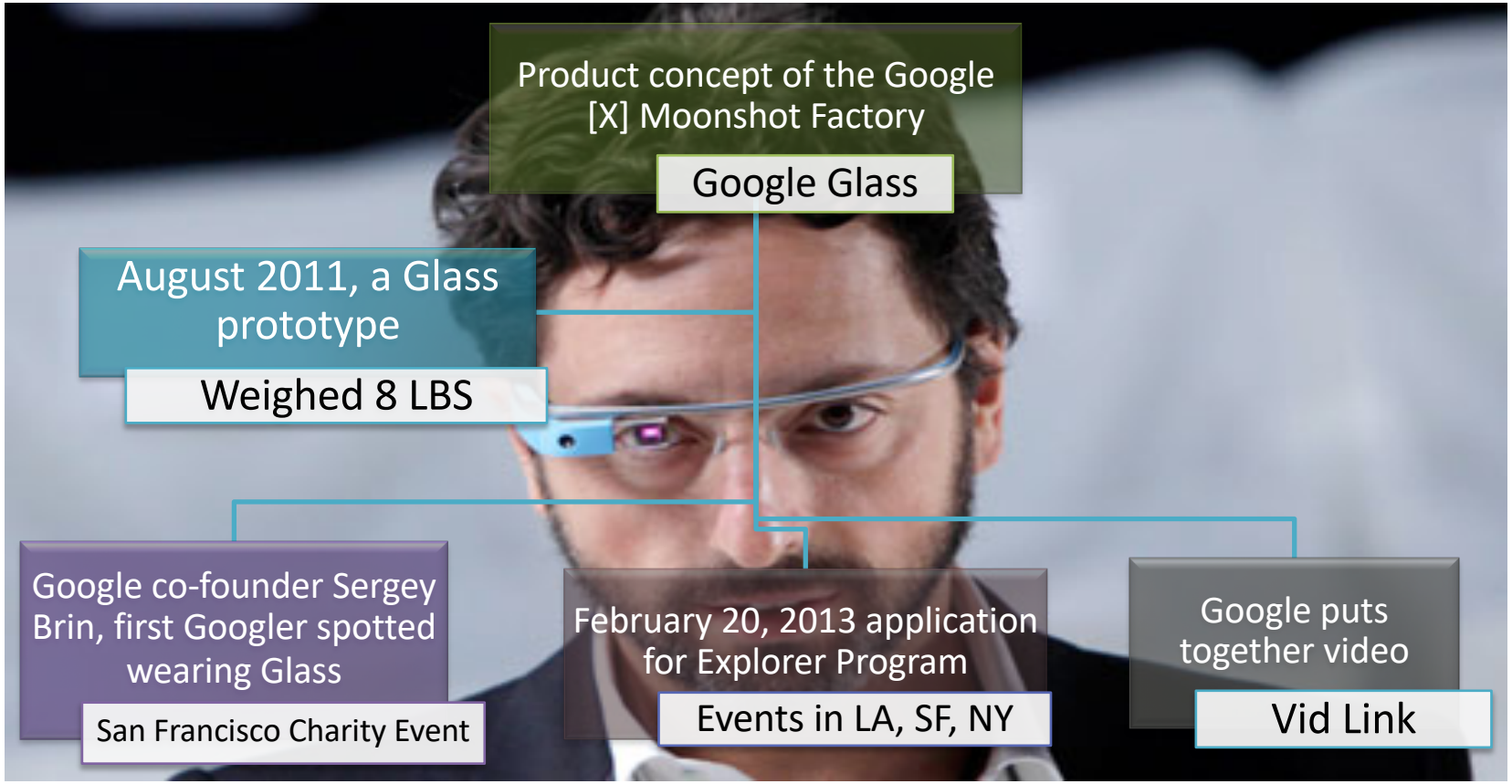
- Safety net
  - Heart rate, perspiration, breath rate
  - Alert friends in case of abnormal values
- Friend finder

Google Glass

- Create a closer relationship with technology.
  - Move away from technology that competes with real life
    - Ex: Take pictures and record videos as you experience them. Allows you to capture the experience and remain in the moment.
  - There when you want it, gone when you don't.
    - Ex: Glass is not in field of vision. Remain connected to what you doing.

By bringing technology closer, we can get it more out of the way.

Development



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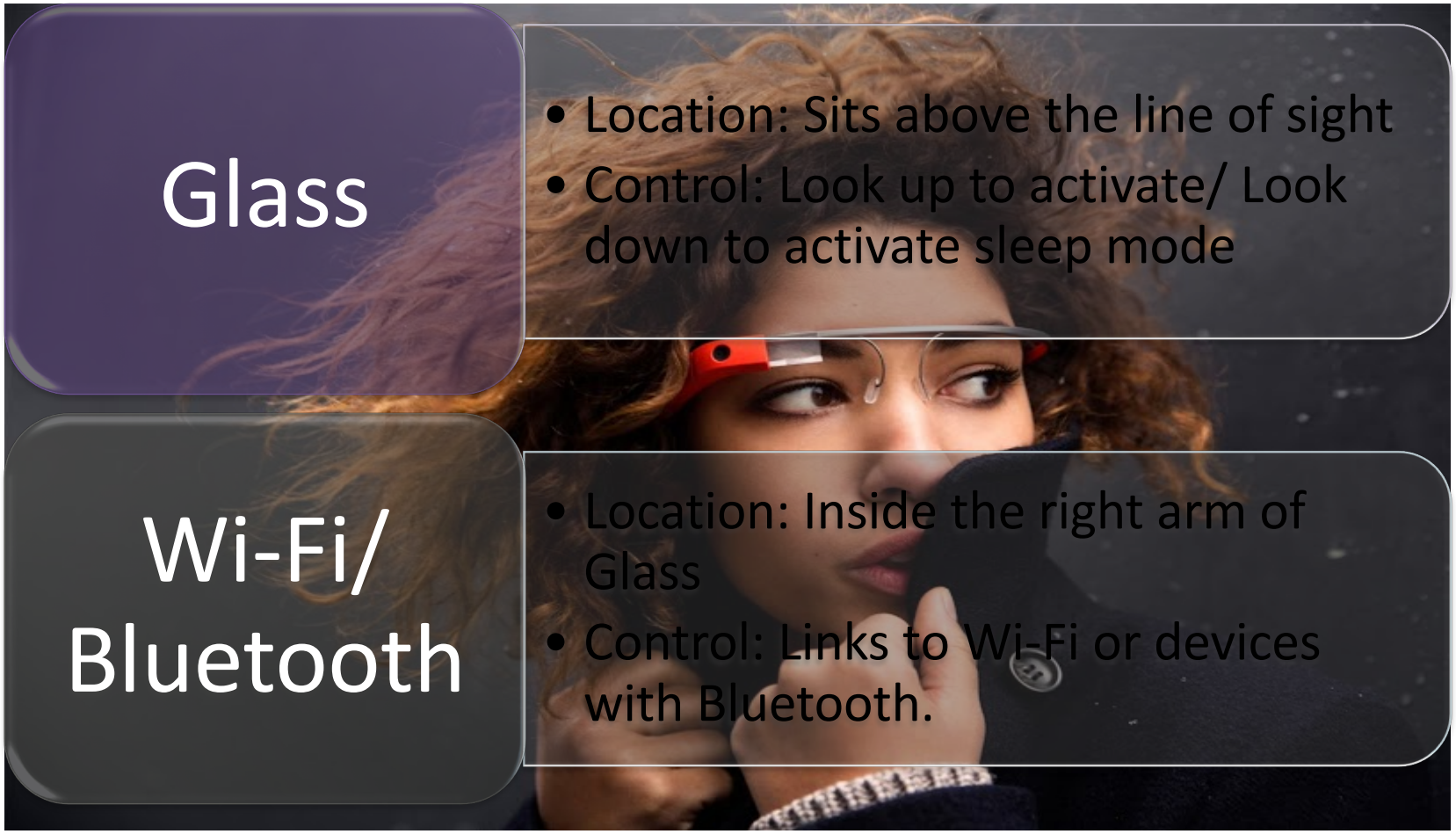
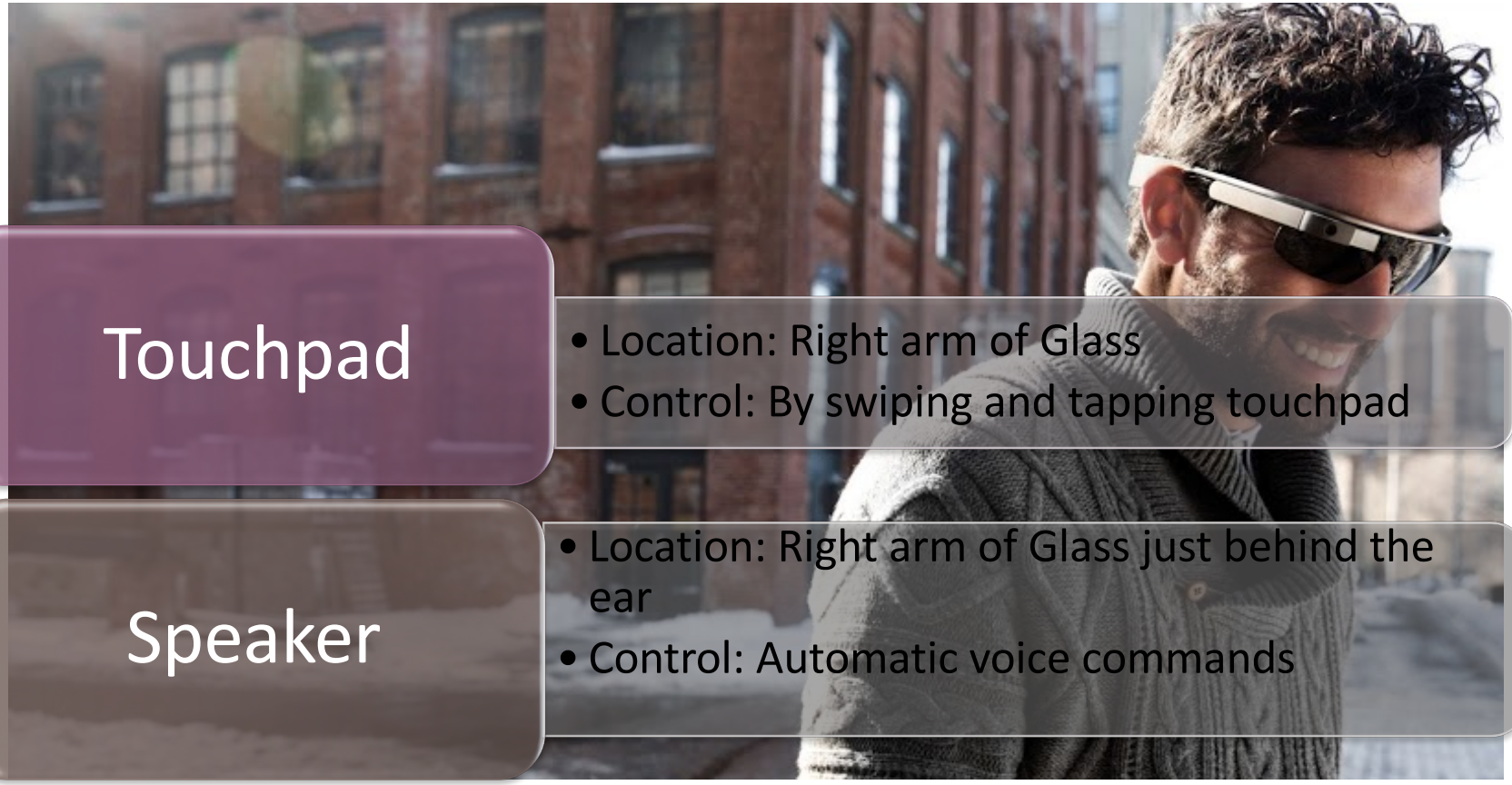
How it worked



How it worked



Touchpad

- Location: Right arm of Glass
- Control: By swiping and tapping touchpad

Speaker

- Location: Right arm of Glass just behind the ear
- Control: Automatic voice commands

Voice Commands

Glass Feature	Voice Command	Explanation
Take Picture	“Ok Glass” take a picture	Hands free and quick
Take Videos	“Ok Glass” take a video	In the moment recording
Video Chat	“Ok Glass” video chat [Person]	Lets others see what your seeing
Send Texts	“Ok Glass” send a text [Person]	Hand free texting like Siri
Translate	“Ok Glass” translates [Word/Phrase]	Translates and recites back with proper pronunciation
Directions	“Ok Glass” give direction to [Place]	Turn by turn directions
Weather	“Ok Glass” what is the weather	Temperature, Chance of Rain and if it is currently sunny or cloudy
Google Hangout	“Ok Glass” hangout [Group Name]	Group interactions with selected friends

Google Glass Enterprise (Version 2)

- Snapdragon 710, LTE modem, Bluetooth 5.0, 802.11ac Wi-Fi, 3GB of RAM, Android Oreo OS, a 32MP camera (4K video at 30fps or 1080p at 120fps)
- Boeing, Brain Power (http://www.brain-power.com/), EyeSucceed (https://www.eyesucceed.com/), Aira (https://aira.io/)

Wearables

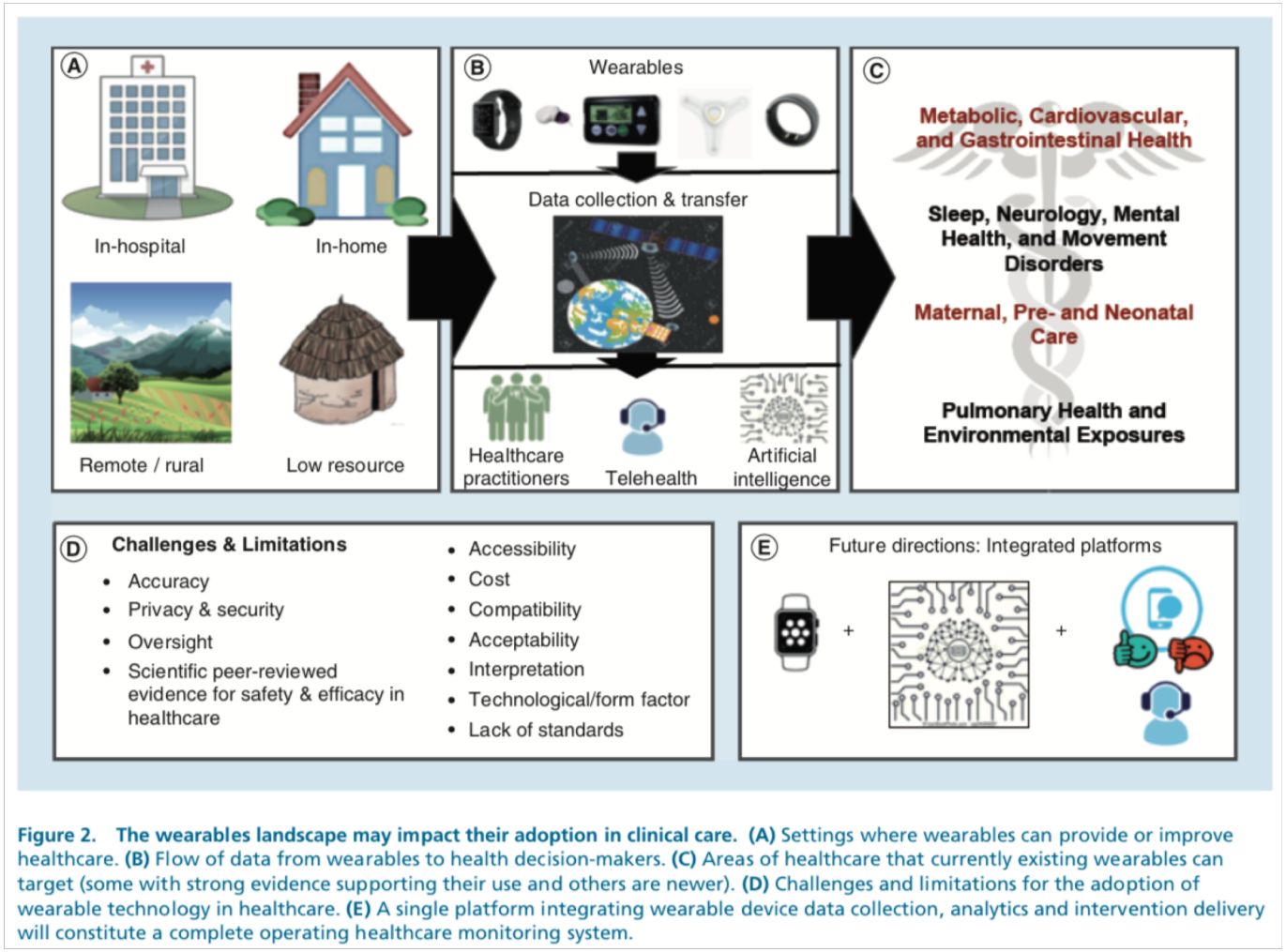
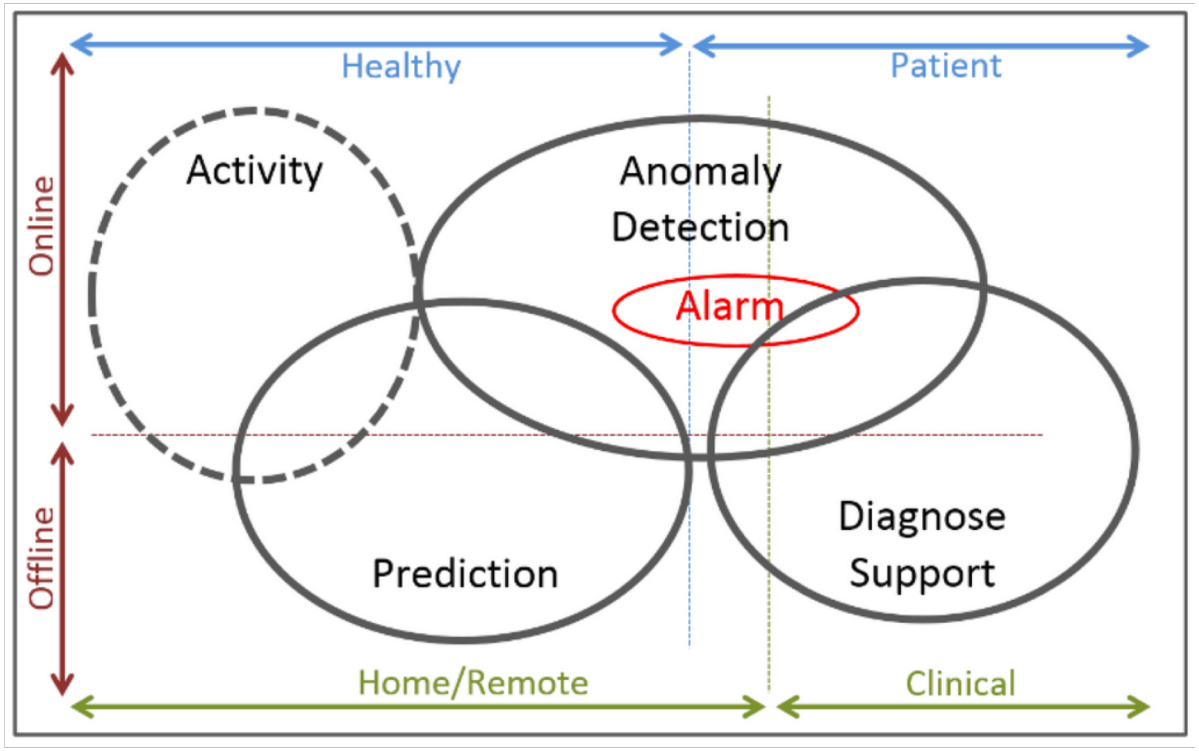


Figure 2. The wearables landscape may impact their adoption in clinical care. **(A)** Settings where wearables can provide or improve healthcare. **(B)** Flow of data from wearables to health decision-makers. **(C)** Areas of healthcare that currently existing wearables can target (some with strong evidence supporting their use and others are newer). **(D)** Challenges and limitations for the adoption of wearable technology in healthcare. **(E)** A single platform integrating wearable device data collection, analytics and intervention delivery will constitute a complete operating healthcare monitoring system.

Vital Signs Sensing

- Vital signs: condition of someone's health; useful in detecting or monitoring medical problems.



Vital Signs Sensing

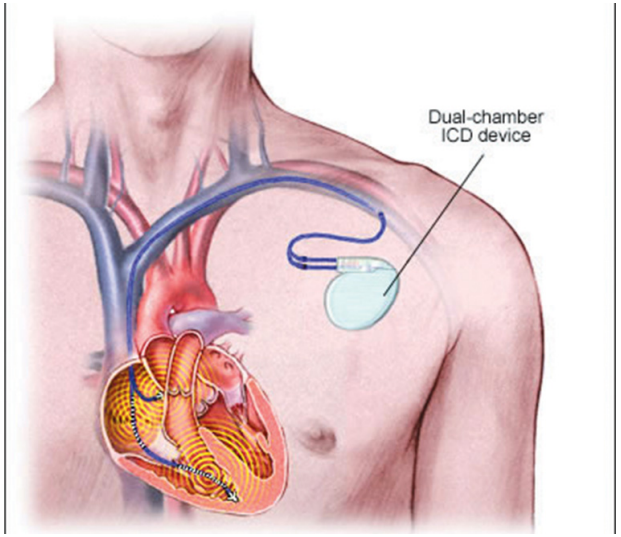
- **Activity area:** fitness, wellness, non-medical applications; self-monitoring; rehabilitation monitoring.
- **Medical area:**
  - **Prediction:** identification of events that have not occurred yet; information to prevent disease; can be used for diagnostic purposes.
  - **Anomaly detection:** identification of unusual patterns; may raise alarm.
  - **Diagnosis support:** obtaining clinical decision; combination of vitals, health records, anomaly detection.

“Valuable” Vital Signs

- Electrocardiogram (ECG)
- Heart rate
- Blood pressure
- Respiration rate
- Blood oxygen saturation (SpO2)
- Blood glucose
- Skin perspiration
- Capnography
- Body temperature

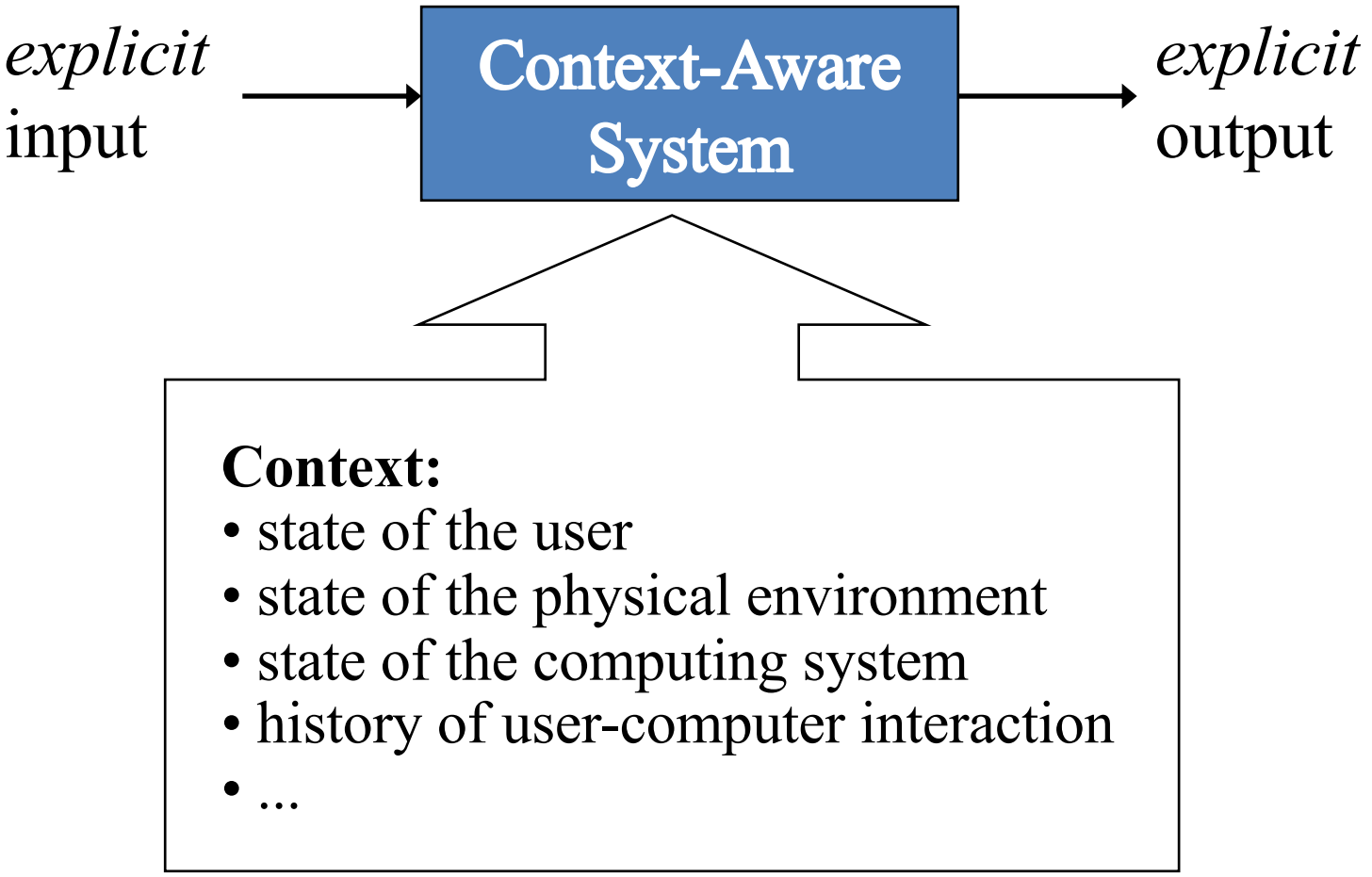
Other Parameters

- Motion evaluation
- Cardiac implantable devices
- Ambiance parameters



System Structure

Context as **Implicit** Input



What is Context?

Examples of Context

- Identity (user, others, objects)
- Location
- Date/Time
- Environment
- Emotional state
- Focus of attention
- Orientation
- User preferences
- Calendar (events)
- Browsing history
- Behavioral patterns
- Relationships (phonebook, call history)
- … the elements of the user's environment that the computer knows about…

Types of Context

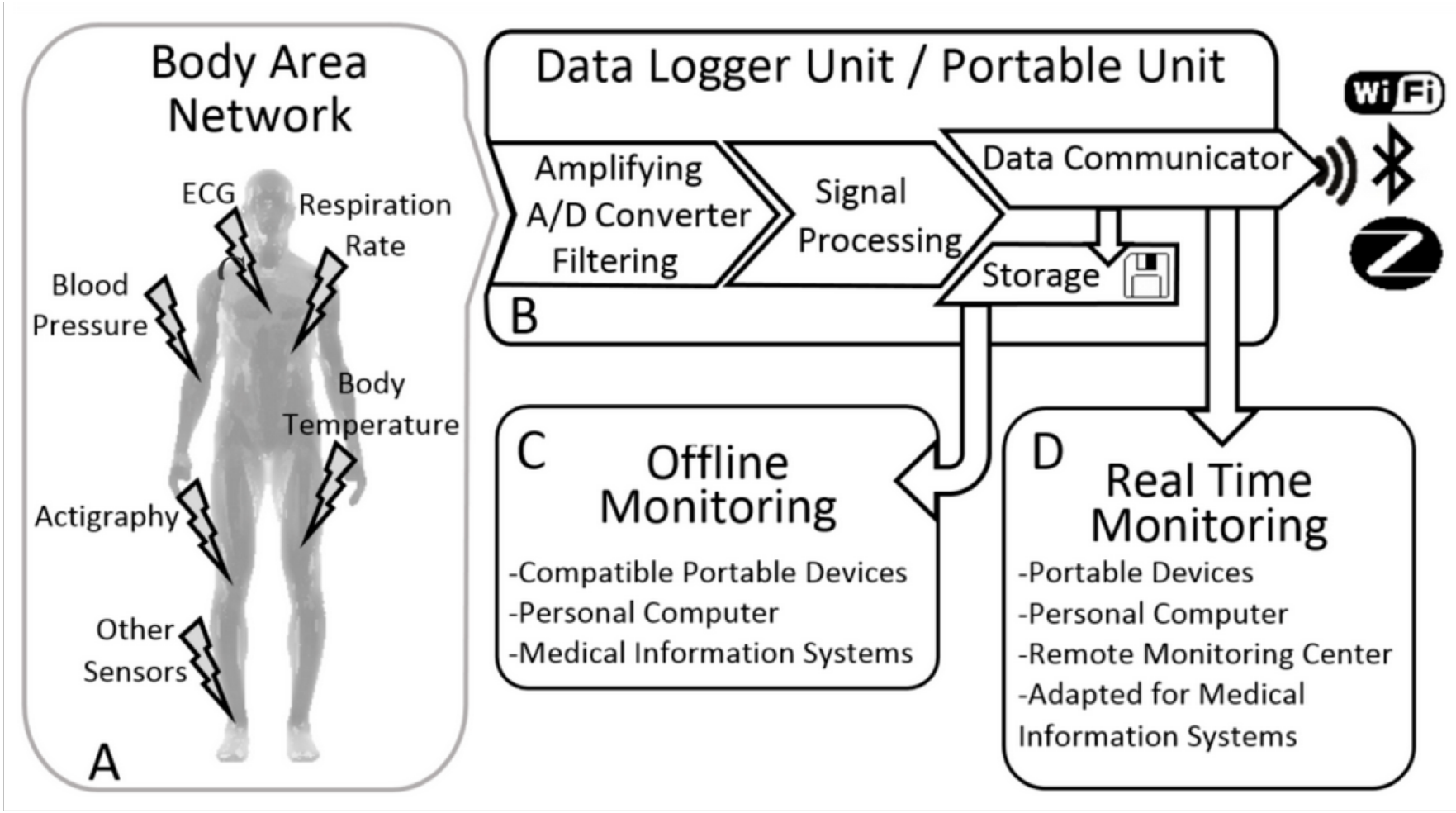
- **Time** Context (current time, day of week, etc.)
- **Physical** Context (location, temperature, pollution levels, noise levels, etc.)
- **User** Context (characteristics, habits, history, etc.)
- **Computational** Context (user input, customer history from database, network status, etc.)

Classification

- **External (physical)**
  - Context that can be measured by hardware sensors
  - Examples: location, light, sound, movement, touch, temperature, air pressure, etc.

- **Internal (logical)**
  - Mostly specified by the user or captured monitoring the user's interaction
  - Examples: the user's goal, tasks, work context, business processes, the user's emotional state, etc.

WHD Architecture

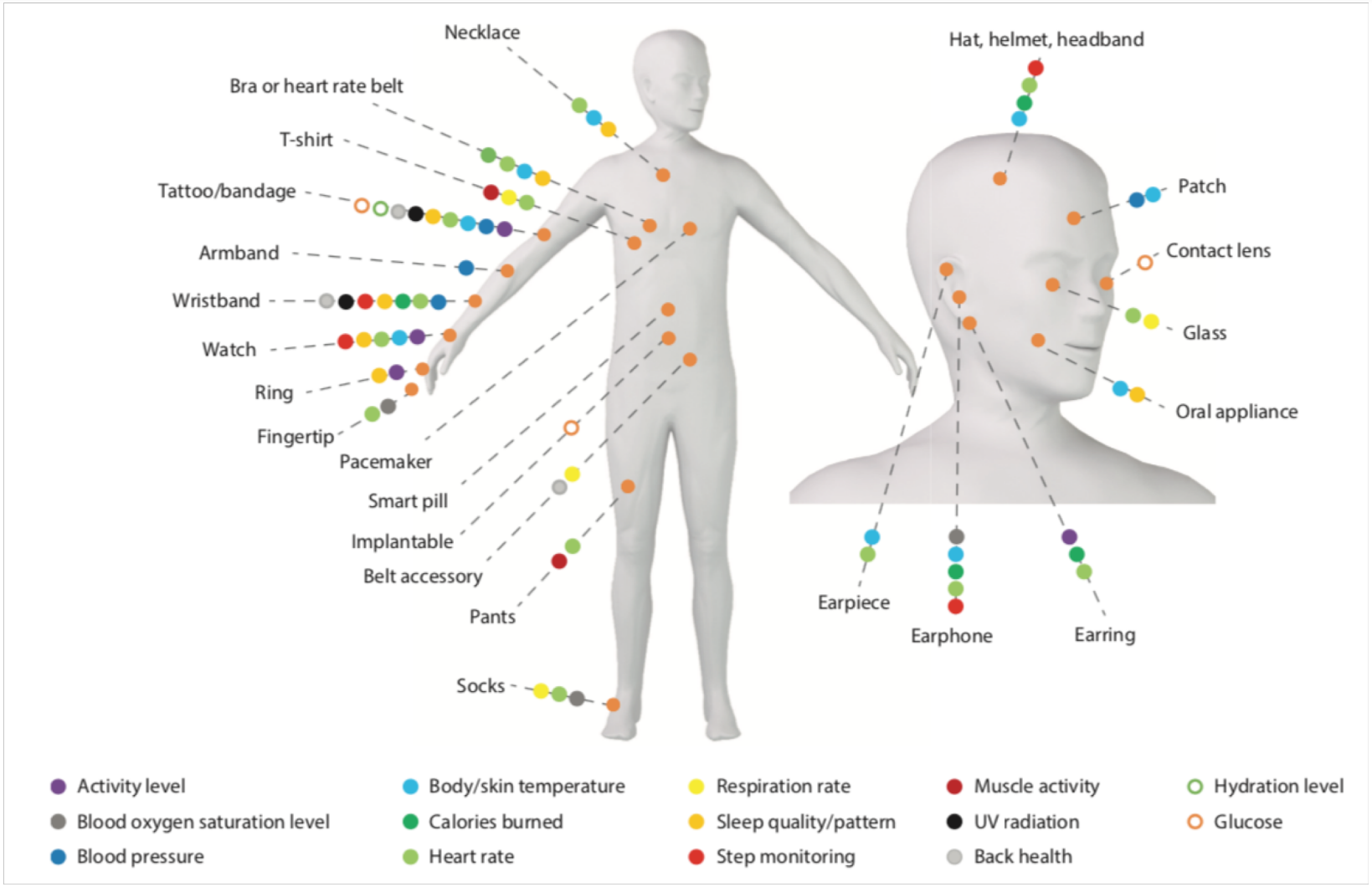


WHD Architecture

- Body area network
- Data logger and portable unit
- Real-time monitoring
- Offline monitoring

Wireless Protocol	Max Range	Max Data Rate	Power Consumption
Bluetooth (before version 4.0)	100 m	1–3 Mbps	2.5–100 mW
Bluetooth Low-Energy (BLE)	100 m	1 Mbps	10 mW
Wi-Fi	150–200 m	54 Mbps	1 W
ZigBee	100 m	250 kbps	35 mW
LoRa	50 km	700 bps	(customizable)

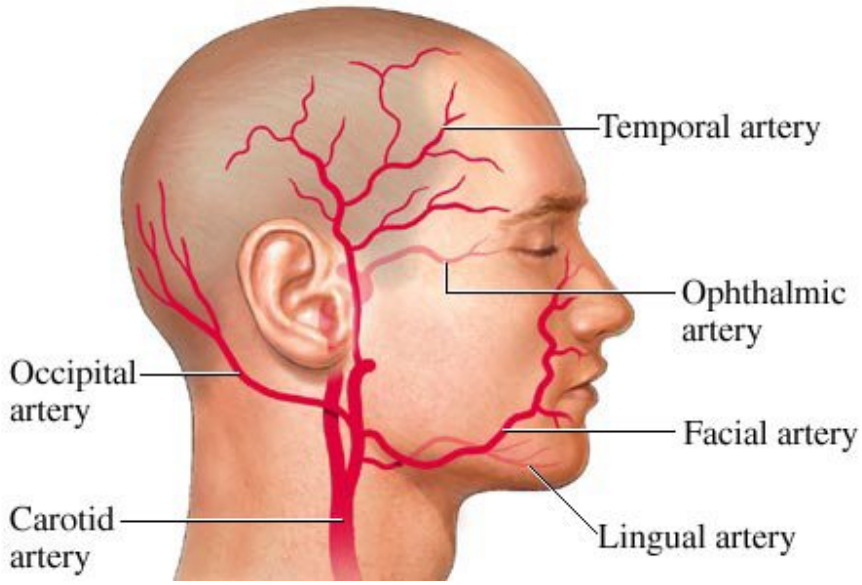
Sensor Placement Options



Sensor Examples

SensoTRACK Ear Sensor

- Heart rate, oxygen saturation, respiration rate, steps, calories burned, activity level, geolocation, body posture, …
- Does not impede motion
- Can minimize device's exposure to ambient parameters
- Easy access to temporal artery
- Can be used for audio replay

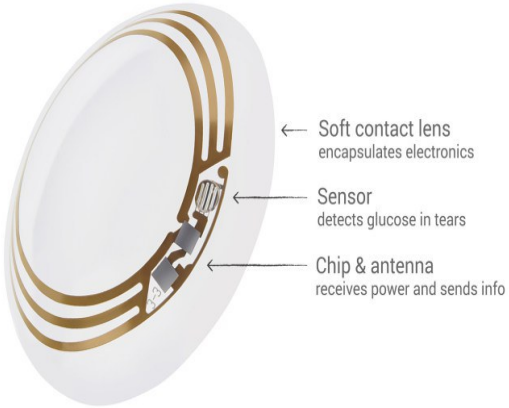


SensoRING

- Blood pressure, PPG, heart rate, ECG, respiration rate, oxygen saturation, activity level, perfusion index.

Google Contact Lens

- Novartis + Google project.
- Lens contains a tiny and ultra slim **microchip** that is embedded in one of its thin concave sides.
- Uses tiny **antenna** to send data about the glucose measurements from the user's tears to smartphone.
- Considered adding LED lighting to warn users when their glucose levels dropped (abandoned due to **arsenic** composition of the LED).
- November 2018: discontinued due to lack of correlation between tear glucose and blood glucose.



Essentials of Tear Fluid

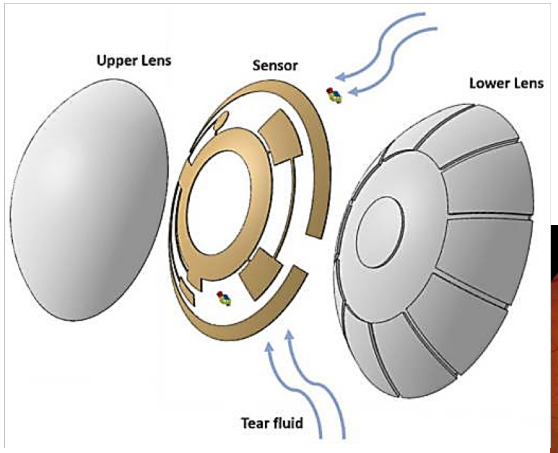
- Among body fluids, tear fluid is a complex multilayered concoction of proteins, lipids, enzymes, and salts. As a result, a variety of biomarkers are present in the fluid and can be potentially used for disease screening.
- In general, the tear film consists of three major layers that functions as a lubricant and cleansing agent for the eye.
- Tear fluid is proven to be a less complex body fluid as compared with serum or plasma because of the blood-tear barrier.

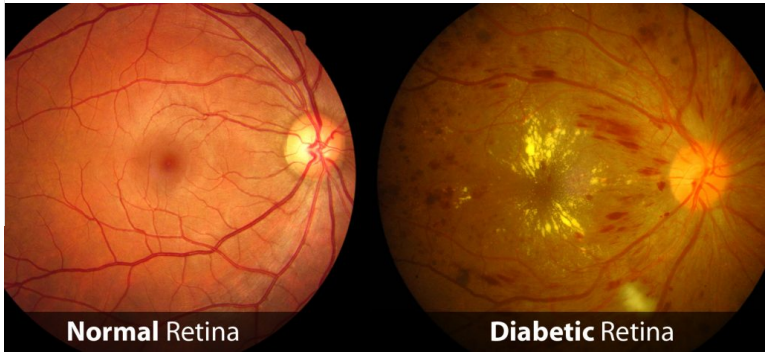
Why Contact Lenses?

- Contact lenses are the most popular wearable devices designed for vision correction, aesthetic, and therapeutic purposes all around the world.
- An estimated population of more than 45 million people in the United States rely on contact lenses daily.
- Blinking and tear secretion also allow for natural, fresh sample replenishment for reliable analyte collection.
- Significant progress in the fabrication process and materials used has increased contact lens accessibility and appeal to consumers, making the cost for daily disposable lenses to be roughly US $1.
- Contact lenses are portable in size and considered minimally invasive medical devices with the capability of integrating a variety of sensing techniques through surface or structural modifications.

Use Cases

- Dry Eye Syndrom
- Diabetes
- Cancers
- Cystic Fibrosis





- Complications:
  - Flow-dependent concentration effects, low sample volumes, and low concentrations of analytes within the fluid all require highly sensitive analysis techniques.
  - Use of medication or supplements by patients (healthy or otherwise), can impact the compositions of tear fluid as well.

BioPatch

- Heart rate, breathing rate, ECG, and posture.

Basis PEAK/Fitbit Versa

- Fitness and sleep tracker

HEALTH & FITNESS

Basis recalls every Peak fitness tracker ever sold after some users sustain burns

QardioCore

- Wireless medical grade (continuous) ECG monitor.
- No shaving, skin abrasion, patches, or adhesives.
- Water-resistant.
- Can communicate with physician.
- For people with increased health risk caused by family predisposition, history of heart attacks or strokes, high blood pressure, high cholesterol, diabetes, and excess weight.

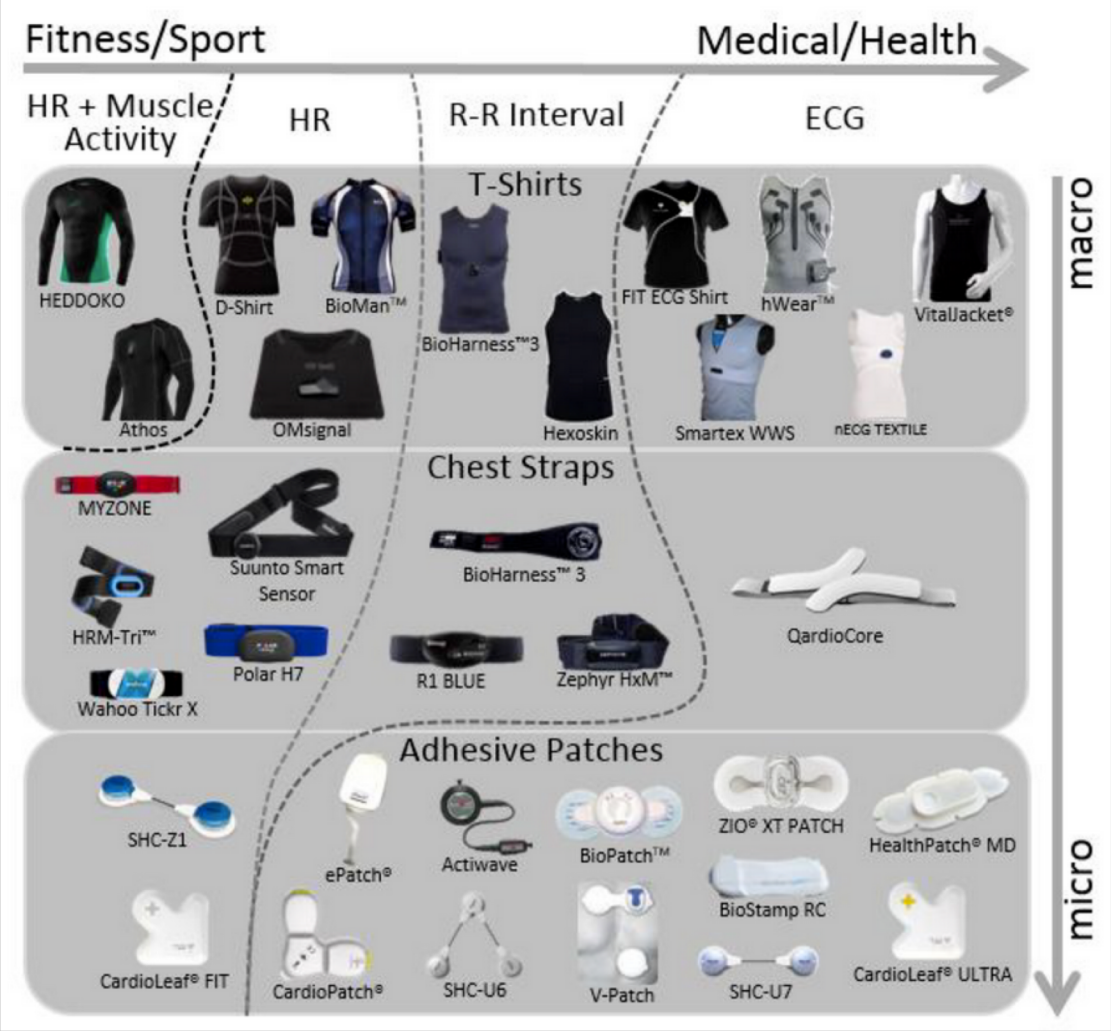
Vital Jacket

- ECG monitor; wirelessly connected.

Moov

- Personal fitness trainer.
- Analyzes form, counts repetitions, measures landing impact, …
- Sweatband version (heart rate).

Heart Activity Trackers



Wearables

Manufacturer	Model	Market	Cost (USD)	Form factor	Sensors	US FDA status	Ref.
Abbott	Libre	Ambulatory diabetes monitoring	149.98 (cost for reader and 10-day sensor)	Semi-invasive	CGM	Approved	[2–4]
AliveCor	Kardia Band	Consumer	199	Wristband	ECG	Cleared	[3–14,15]
Apple	Watch Series 3	Consumer	329	Watch	Accel, ambient light sensor, BALT, Gyro, PPG HR, GPS	Precertified	[3–16]
Ava Science, Inc.	Ava Wristband	Consumer	249	Wristband	Accel, EDA, PPG HR, temperature sensors	Approved	[17]
BACtrack	Skyn	Pre-Market	–	Wristband or watch	Transdermal	–	
Bloomlife	Smart Pregnancy Tracker	Consumer (rental)	20/week	Abdominal patch	Accel, 3-channel AFE	–	[17,18]
Dexcom	G5 Mobile	Ambulatory diabetes monitoring	1016 (cost for transmitter, receiver, 4-pack of replaceable sensors)	Semi-invasive	CGM	Approved	[2,19]
Empatica	Embrace	Consumer	249	Watch	Accel, EDA, Gyro, peripheral temperature sensor	Approved	[20,21]
Fitbit	Charge	Consumer	149.95	Watch	Accel, PPG HR	Precertified	[22]
GI Logic	AbStats	Premarket	–	Abdominal device	Vibration, acoustic	–	[23]
G-Tech Medical	G-Tech Medical	Premarket	–	Abdominal patch	EMG	–	[24,25]
Health Care Originals	ADAMM-RSM	Premarket	–	Chest patch	Acoustic, HR, temperature	–	[26–28]
iRhythm	Ziopatch	Ambulatory cardiac monitoring	Ordered through physician, billed directly to insurance	Chest patch	ECG	Cleared	[29,30]
Med/Wise	Gluco Wise	Premarket	–	Clip (thumb, forefinger or earlobe)	CGM Radio wave sensor	–	
Medtronic	Enlite	Ambulatory diabetes monitoring	–	Semi-invasive	CGM	Approved	[5,31]
Motiv	Motiv Ring	Consumer	199	Ring	Accel, PPG HR	–	
Omron	Heart Guide	Premarket	–	Watch	Accel, PPG HR, oscillometric blood pressure	–	[32]

Wearables

Orpyx	Surro Gait Rx	Ambulatory gait monitoring	Ordered through physician	Watch, shoe insert, shoe pod	Pressure	–	[33
]Orpyx	Surro Sense Rx	Ambulatory gait monitoring	Ordered through physician	Watch, shoe insert, shoe pod	Pressure	Cleared	[34]
Oura	Oura Ring	Consumer	299–999	Ring	Accel, Gyro, PPG HR, skin temperature	–	[35]
Preventice	Bodyguardian Heart	Ambulatory cardiac monitoring	Ordered through physician billed directly to insurance	Chest patch	Accel, ECG	Cleared	[36]
Sentio Solutions	Feel	Premarket	149	Wristband	EDA, PPG HR, skin temperature	–	[37]
Tempdrop	Tempdrop	Consumer	150	Underarm armband	Thermometer	–	
Verily	Alcon	Premarket	–	Smart lens	CGM	–	
VitalConnect	Vital Patch	Premarket	–	Chest patch	Accel, ECG, thermistor	Cleared	[11]
Yono	Earbud	Consumer	149.99	Earbud	Thermometer	–	
Zoll	Lifevest	Ambulatory cardiac monitoring/intervention (rental)	3–4k	Vest	ECG	Approved	[38]

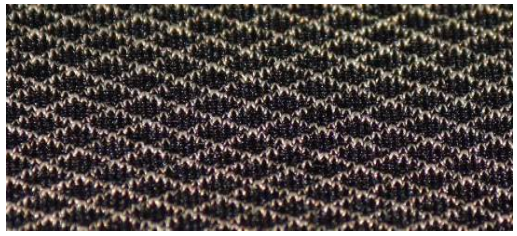
Accel: Accelerometer; AFE: Analog front end; BALT: Barometric altimeter; CGM: Continuous glucose monitor; ECG: Electrocardiography: EDA: Electrodermal Activity; EMG: Electromyography; GPS: Global positioning system; Gyro: Gyroscope; HR: Heart rate; PPG: Photoplethysmography; Therm: Thermometer.

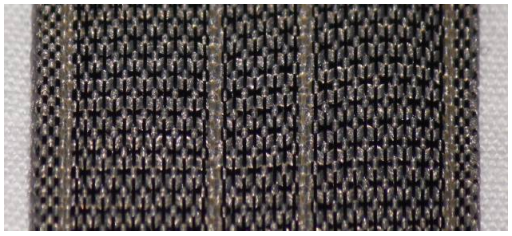
Georgia Tech Smart Shirt

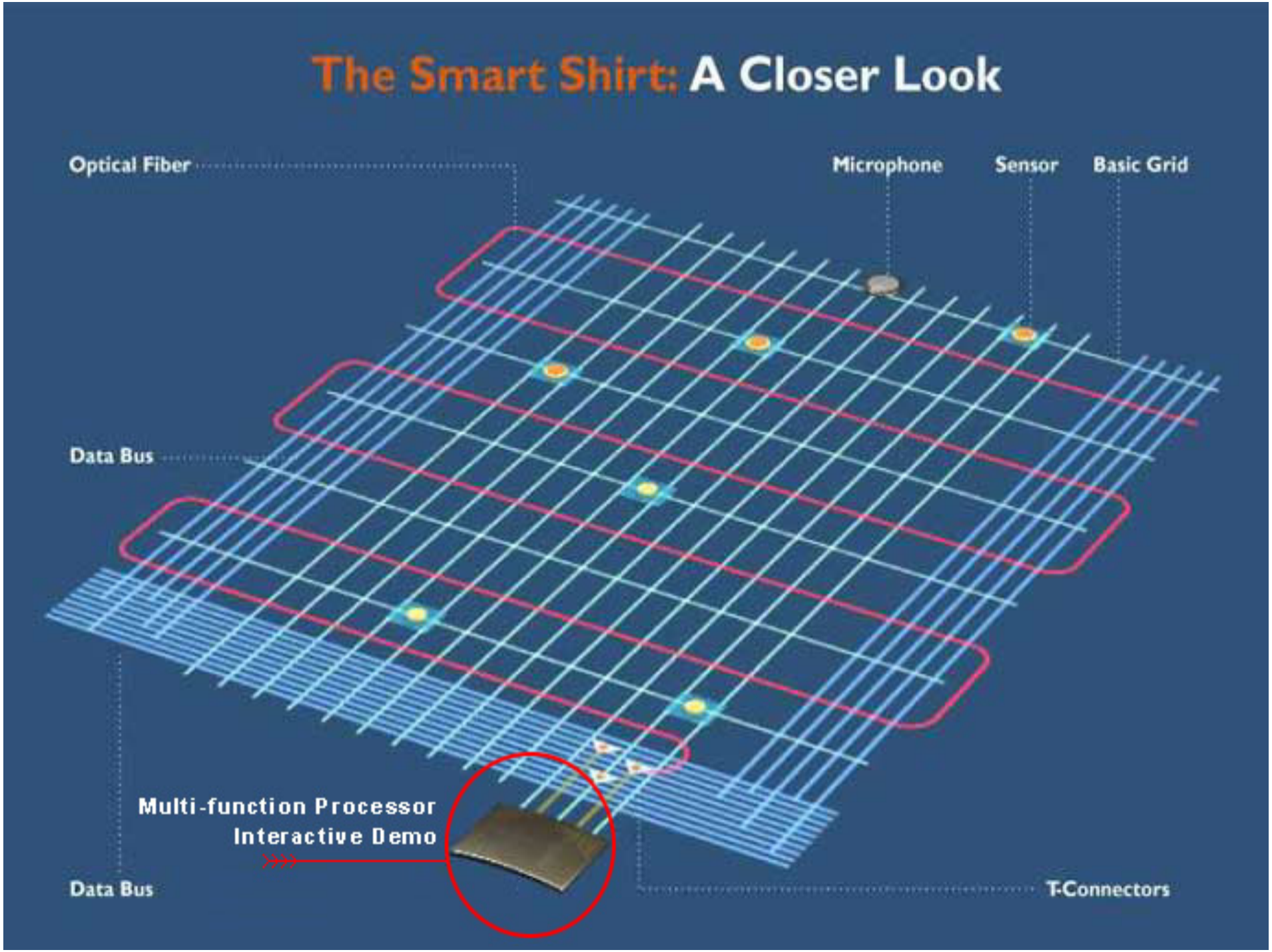
- Combat casualty care.
- Optical fibers detect bullet wounds.
- Sensors monitor vitals.
- Sensors can be plugged into fabric (which serves as “motherboard”).

Textile Electrodes

- Textile electrodes/sensors are used for collecting data from the body.
- Consists of traditional textile fibers (natural or synthetic) and electrically conductive elements (metal, conductive polymer, carbon, graphene)






The Smart Shirt: A Closer Look
Optical Fiber
Microphone
Sensor
Basic Grid
Data Bus
Multi-function Processor
Interactive Demo
Data Bus
T-Connectors

Application Areas of Conductive Textiles

- Body/vitals monitoring
- Signal and power transfer
- Heating (arctic shirts)
- Antennas
- Sensors and actuators
- EMI-shielding
- Prevent electro static dissipation (ESD)

Advantages

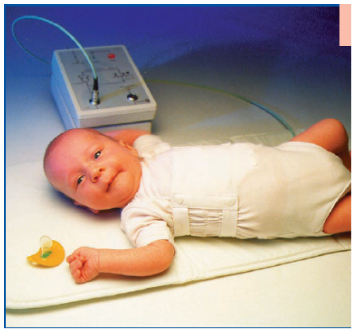
- Enable perfect electrode/sensor placement and shape.
- Flexibility of electrodes guarantees proper skin contact.
- Cables and wires can be invisibly integrated into textile.
- System invisibility (and low weight, washability, etc.) makes it acceptable for the user.
- Comfortability and softness of electrodes enable long time measurement.

Biosignals

- Heart rate, heart rate variability, heart activity (ECG)
- Stress level and sleep quality (ECG)
- Brain function and vitality level (EEG)
- Muscle rate and balance (EMG)
- Body motions and postures (EMG)
- Body composition; fat content and fluid balance (EBI)
- Lung function (EIT)
- Respiration rate and frequency
- Skin conductivity
- Skin temperature

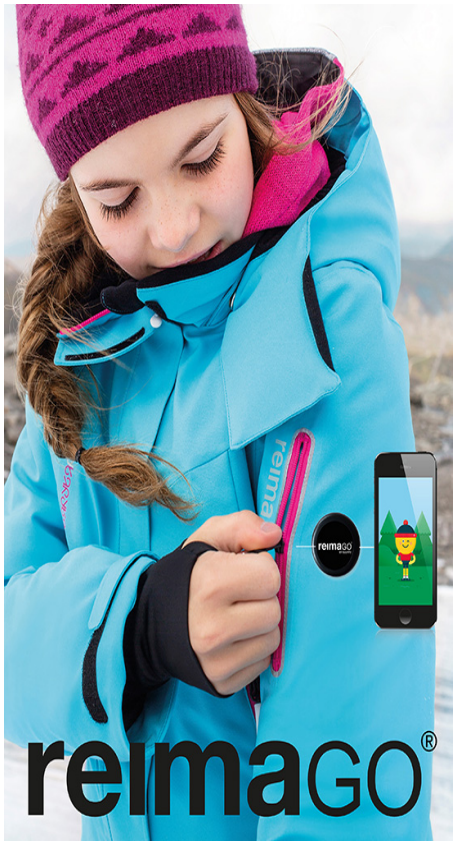
Example: Sudden Infant Death Syndrome

- SIDS is sudden, unexpected death of baby; caused by breathing failure.
- Pyjamas with built-in sensors, signal processing, and data collection unit.
- Track baby's heart rate and breathing patterns with multiple sensors.
- When a problem is detected pyjama sounds an alarm.



Example: Child Tracker

- Durable, washable ReimaGO® activity sensor by Suunto can be attached to Reima outerwear using a special pocket with laminated Movesense press studs.
- The sensor wakes up when the wearer starts to move.
- Parents see kids' activity scores in a mobile app.
- The app also has a fun kids' interface through which rewards can be gained.



Example: Firefighter Jacket

- Thermal sensors embedded into fabric.
- Visually indicate critical heat levels to the firefighter in action and his colleagues before it's too late.
- The thermal sensors monitor the outer temperature near the fire-fighter and on the inside of the coat close to the body.
- The sensors are attached to two LED displays, on the sleeve and one on the back.

Potential and Opportunities

- The interest towards long term wearable home monitoring (mHealth) applications is growing.
- Long-term monitoring could be used for:
  - Pre-emptive actions for risk groups
  - Chronic disease progression
  - Assessing health after surgery or injury
  - Rehabilitation after surgery or injury

- Almost a billion people worldwide suffer from at least one chronic disease; it is believed that 25% of them would benefit from a wireless home monitoring system.

Implantable Medical Devices

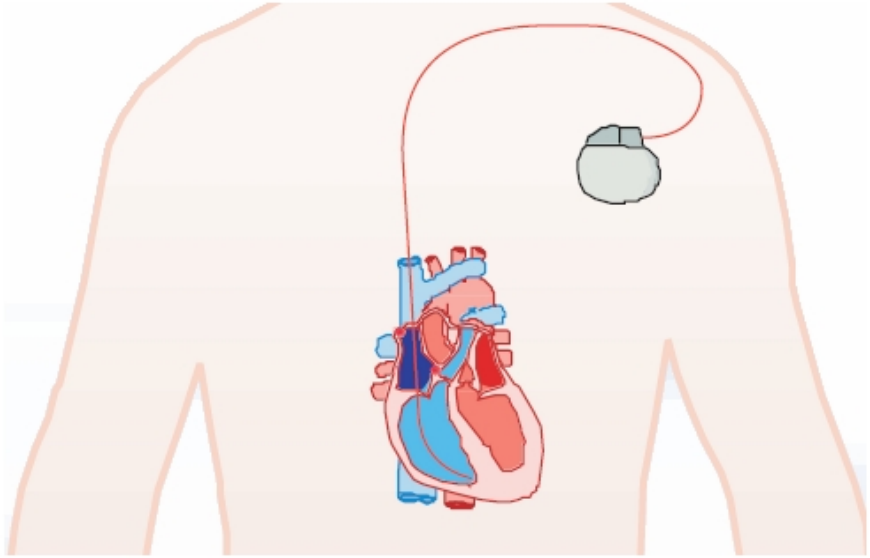
- Two main functions:
  - Applying a therapy, usually by delivering electrical signals to some organs or tissues.
  - Monitoring relevant parameters or signals in order to avoid risks to the patient or to optimize his treatment.
- They usually are capable of measuring and analyzing electrical and mechanical physiological signals and transmit this information or use it as input data for the therapy.

Market Situation

- 5 big companies:
  - Share more than 98% of the market (mainly pacemakers and ICDs).
  - Buy patents and technology from small companies in the field or eventually buy smaller companies.
- Start–up companies:
  - Investigate feasibility of treating a disease using an implantable device implementing a therapy conceived by themselves.
  - Few per year, mainly from US, Israel, and Canada.
  - Without capacity to develop and manufacture the devices.

Cardiac Pacemaker (ICD)

- Since 1960!



Cochlear Implants

Functional Electrical Stimulation

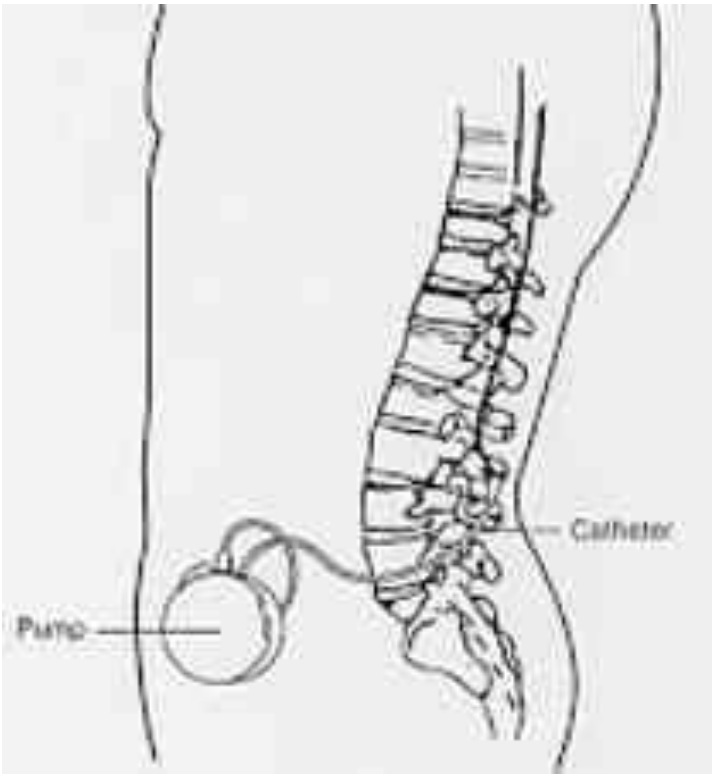
FES

Functional electrical stimulation is a treatment that applies small electrical charges to the leg to improve mobility in people who have difficulties with walking arising from damage in their brain or spinal cord.

Multiple Sclerosis Trust MS

Read more at mstrust.org.uk/fes

Implantable Infusion Pump

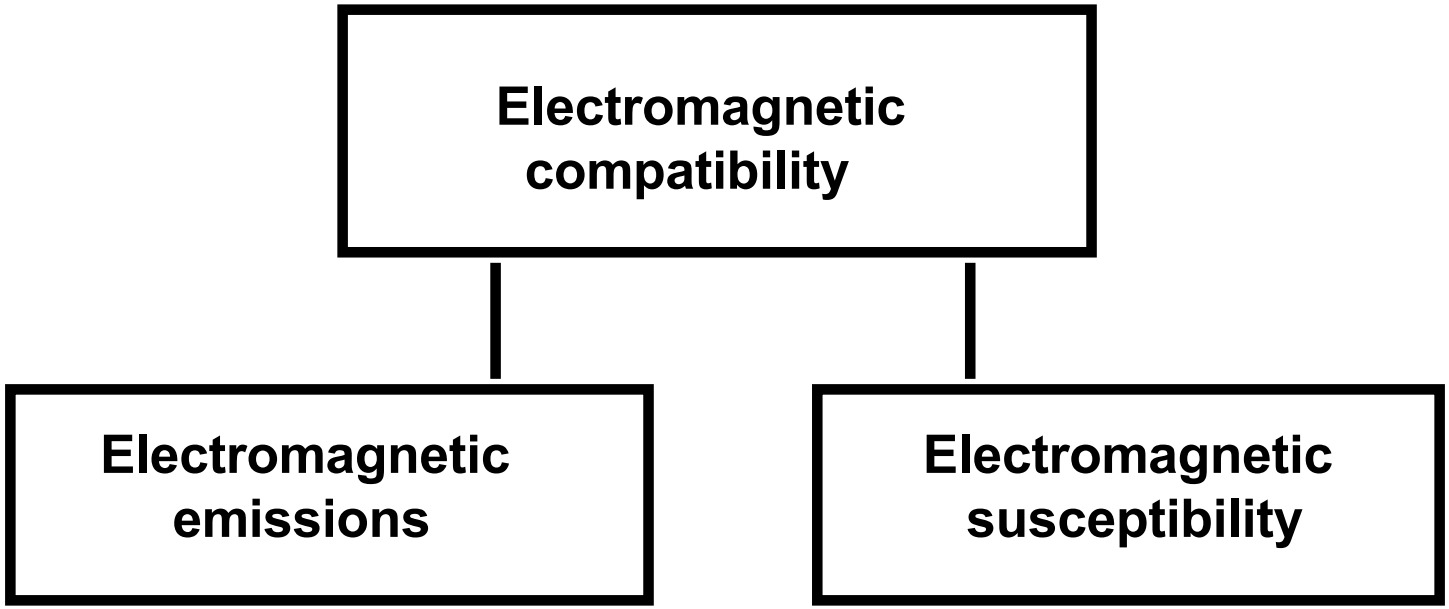


Risk: EMC

- Electromagnetic Compatibility (EMC):
  - When equipment is performing its designed functions without causing or suffering unacceptable degradation due to electromagnetic interference to or from other equipment.
- Common sources of interference:
  - Radio/TV stations
  - Remote controls
  - Cell phones
  - Microwaves*
  - Appliances*
  - Light dimmers*

  * unintentional

Risk: EMC


Electromagnetic compatibility
Electromagnetic emissions
Electromagnetic susceptibility

Limits USA (FCC)

FCC Class A Conducted EMI Limit	
Frequency of Emission (MHz)	Conducted Limit (μV)
0.45 - 1.6	1000
1.6 - 30.0	3000
FCC Class B Conducted EMI Limit	
Frequency of Emission (MHz)	Conducted Limit (μV)
0.455 - 1.6	250
1.6 - 30.0	250
FCC Class B 3-Meter Radiated EMI Limit	
Frequency of Emission (MHz)	Field Strength Limit (μV/m)
30 - 88	100
88 - 216	150
216 - 1000	200
above 1000	200
FCC Class A 10-Meter Radiated EMI Limit	
Frequency of Emission (MHz)	Field Strength Limit (μV/m)
30 - 88	90
88 - 216	150
216 - 960	210
above 960	300

Federal Communications Commission (FCC)

Limits Europe (CISPR)

CISPR Class A Conducted EMI Limit		
Frequency of Emission (MHz)	Conducted Limit (dBµV)	
	Quasi-peak	Average
0.15 - 0.50	79	66
0.50 - 30.0	73	60
CISPR Class B Conducted EMI Limit		
Frequency of Emission (MHz)	Conducted Limit (dBµV)	
	Quasi-peak	Average
0.15 - 0.50	66 to 56*	56 to 46*
0.50 - 5.00	56	46
5.00 - 30.0	60	50
CISPR Class A 10-Meter Radiated EMI Limit		
Frequency of Emission (MHz)	Field Strength Limit (dBµV/m)	
30 - 88	39	
88 - 216	43.5	
216 - 960	46.5	
above 960	49.5	
CISPR Class B 3-Meter Radiated EMI Limit		
Frequency of Emission (MHz)	Field Strength Limit (dBµV/m)	
30 - 88	40	
88 - 216	43.5	
216 - 960	46.0	
above 960	54.0	

**Decreases with the logarithm of the frequency.*

International Special Committee on Radio Interference, or CISPR

EMC Threats

Device Type	Power (W)	Frequency (MHz)	In Vivo Studies			In Vitro Studies
			Health Canada	Univ. of Oklahoma	U.S. FDA	
Analog Cellular Phone	0.6	828	0%	0%	0	0.5%
TDMA-50	0.6	835	3.4%	4.7%	10%	4.2%
TDMA-11	0.6	—	—	—	36.7%	10.5%
CDMA	0.6	—	—	2.8%	—	3.1%
PCS	0.6	1810	0%	0.6%	—	0.2%
GSM	0.6	—	—	—	0	—
FRS	0.1	468	0%	—	—	—
Number of Pacemakers	—	—	20	29	30	975 patients
Incidence of Interference	—	—	3.4%	4.7%	—	20%

Table II. Effects of various wireless telecommunications devices on pacemakers (in vitro and in vivo studies).

EMC Threats

Type	Mode	Carrier Frequency	Magnetic Field Strength (μT)*	Effects on Pacemakers	
				Inhibition	Reactivation
EAS	Continuous	535 Hz	450	23%	55%
	Modulated pulse	Carrier: 58.4 KHz modulation:60 Hz	400	36%	68%
	Sweep	7.4–9.1 MHz	0.1	0	0
WTMD	Pulse	250–500 Hz	4.5–10	5%	9%
	Pulse	89 Hz	45	36%	64%
	Modulated pulse	250–909 Hz	18–22	5%	9%
	Modulated pulse	210 Hz	12	9%	14%
HHMD	Continuous	14 kHz–1.8 MHz	0.2–10	0	0

*Measured at 15 cm from the transmission panel of EAS and WTMD systems and 2.5 cm from HHMDs; 0 indicates no interference effects.

Table III. Effects of security systems on pacemakers.

EMC Threats

Implant → / Potential Interferer ↓	Implanted Cardiac Pacemaker	Implanted Cardiac Defibrillator	Implanted Neurostimulator
Shortwave and Microwave Diathermy	Absolute contraindication	Absolute contraindication	Absolute contraindication
Ultrasound Diathermy	Take Precaution*	Take Precaution*	Absolute contraindication
Electromagnetic Stimulation Device	Take Precaution*	Take Precaution*	Absolute contraindication
MRI	Absolute contraindication	Absolute contraindication	Absolute contraindication
Electrosurgery Device	Take Precaution*	Take Precaution*	Take Precaution*
External Defibrillator	Take Precaution*	Take Precaution*	Take Precaution*
Radiotherapy Device	Take Precaution*	Take Precaution*	Take Precaution*
Lithotripsy or Ultrasound Therapy Device	Take Precaution*	Take Precaution*	Take Precaution*
Fluoroscopy or other X-ray Devices	No contraindication	No contraindication	No contraindication
Echography	No contraindication	No contraindication	No contraindication

EMC Threats

- MRI:
  - Magnetic field strengths of 0.3T to 3T (earth's magnetic field is ~ 50μT).
  - 2006 classification for implant and ancillary device safety (ASTM/FDA):
    - **MR-Safe –** device or implant is completely non-magnetic, non-electrically conductive, and non-RF reactive.
    - **MR-conditional –** may contain magnetic, electrically-conductive or RF-reactive components found safe in tested conditions ("tested safe to 1.5T").
    - **MR-unsafe**